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Free-Radicals Research Program

A THREE-YEAR PROGRAM of basic research on free radicals has been undertaken by the National Bureau of Standards. The object of the program will be to increase fundamental knowledge of the formation, properties, and storage of these highly reactive molecular fragments. Plans have been made for a series of experimental and theoretical investigations, which, it is hoped, will not only provide valuable data but will also stimulate new areas of research in this important new field. The work is receiving support from the Department of Defense through the Office of Ordnance Research, U. S. Army.

The free-radicals research program will consist of many separate projects to be carried out in various laboratories of the Bureau, and much of the investigative work will be done by scientists on loan from industrial laboratories. However, over-all direction and coordination will be centered in a Free Radicals Research Section recently established for this purpose.

Ordinarily free radicals exist only for very short periods in systems such as flames and hot gases. However, within the past 5 years numerous methods have been developed in a number of laboratories for capturing and storing them, mainly at low temperatures. Recently, by freezing the products of an electric discharge at a few degrees above absolute zero, scientists at the Bureau were able to store some types of free radicals in highly excited states, making it possible to study and analyze them by spectroscopic methods.[1] Free-radical storage techniques now promise to provide an important tool for the study of atomic and molecular physics and for research in basic chemistry. However, before these applications can be seriously considered, much additional research must be done on free radicals of all types in order to provide information on such topics as their properties in solid, liquid, and gaseous phases; their recombination rates at various temperatures; and their reactions with other materials. The free-radicals program was set up to provide an integrated approach to these problems.

To encourage broad dissemination of the information obtained in the program, and also to minimize interference with other established projects at the Bureau, participating scientists will be drawn largely from other institutions. Approximately half of the technical staff for the free-radicals research program will be on loan from industrial research laboratories, working under a unique cooperative plan. Others will come from universities and various Government agencies.

The guest scientists will be selected for participation on the basis of competence in their field and interest in the new research problems. It is expected that the work of this central research group will be continued and expanded in many of the industrial laboratories after termination of the present program.

Insofar as possible, each visiting scientist will be assigned to the Bureau laboratory most closely allied with his field of interest. There he will work with colleagues and facilities in his special field while re-

taining the advantage of close cooperation with the remainder of the staff of the free-radicals research program throughout the Bureau.

A technical-data center is being set up so that free-radical research at other laboratories, both in the United States and abroad, may be closely followed. Other activities serving to knit together the various research projects making up the program will include weekly colloquia and a general conference now being planned for mid-1957.

Although the free-radicals research program is still largely in the planning stage, a number of projects are already under way. These include spectroscopic investigations of condensates from electric discharges; X-ray and electron-diffraction studies of the structure of solids containing free radicals; methods of preparing pure free radicals by photolysis and gamma irradiation; and theoretical calculations of recombination rates, heats of reaction, and other properties.

Herbert P. Broida, who has been named Chief of the new Free Radicals Research Section, will serve as technical coordinator for the entire program. Arnold M. Bass is to serve as Assistant Chief of the Free Radicals Research Section. James W. Moyer will serve as consultant for the program, and A. K. Stober, formerly of the NBS cryogenic physics laboratory, will assist with low-temperature experiments. Robert D. Huntoon, Associate Director for Physics, will have over-all responsibility for the program.

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[1] Low temperature storage of free radicals, *NBS Tech. News Bul.* **40**, *112* (*August 1956*).

Spectrographic Standard Samples of Zinc-Base Alloys

SIX new spectographic standard samples of zinc base alloys are now available from the Bureau. Carefully analyzed and certified as to composition, the new standards are designed for calibrating and checking spectrochemical methods in the analysis of two important zinc-base die-casting alloys (ASTM designations AG40A and AC41A).

For each of the two alloys, three standards have been issued to provide the necessary composition ranges for the elements covered by specifications; namely, aluminum, copper, magnesium, iron, lead, cadmium, and tin. The standards also contain useful concentration ranges for chromium, manganese, nickel, and silicon.

In recent years, high-speed spectrochemical methods of analysis have been extensively adopted by both producers and consumers of metal products. In each field of application, these newer techniques have brought about a need for standard samples for calibration purposes. Several years ago it became apparent that spectrographic standards of accurately determined composition and high homogeneity were urgently needed in the zinc die-casting industries. On learning late in 1952 that the General Motors Corp. intended to prepare a series of zinc-base standards for use within the corporation, the Bureau proposed that the program be expanded to provide nationally available standards for the alloys. The cooperative program that was adopted followed a pattern of similar programs in the past, but was unique with respect to the close cooperation in all phases of the work from the planning through the final analytical stage.

The zinc-base standard samples are available as bar segments $1\frac{3}{4}$ in. square and $\frac{3}{4}$ in. thick. In this form the sample serves as a self electrode in opposition to a high-purity graphite electrode for electrical excitation in spectrographic analysis. The material was melted and chill-cast into bars by a special continuous casting process at the Chicago Branch of the National Lead Co.

The homogeneity of the standard materials was investigated both at NBS and at General Motors Corp. The Bureau used spectrochemical methods while General Motors employed both chemical and spectrochemical techniques. The results showed that the standards exhibit satisfactory homogeneity for the specified portion of each sample, that is, the portion included between $\frac{3}{16}$ in. and $\frac{11}{16}$ in. from each side of the square section of the sample. (The center core, $\frac{3}{8}$ in. square, and a layer at the periphery, $\frac{3}{16}$ in. thick, are portions that may differ in composition from the certified portion for some elements.)

Chemical analyses on millings representing the certified portion of the bars were made by six cooperating laboratories: Apex Smelting Co.; General Motors Corp. (Research Division); Hudson Bay Mining & Smelting Co., Limited; Metal & Thermit Corp.; New Jersey Zinc Co.; and NBS.

The zinc-base standards may be obtained from the Bureau for a fee of $8.00 each. A provisional certificate supplied with the standards gives average values of the analyses reported by the cooperating laboratories. The compositions of the standards are given in table 1.

TABLE 1. *Composition of NBS zinc-base spectrographic standard samples*

NBS No.[a]	Designation	Cu	Al	Mg	Fe	Pb	Cd	Sn	Cr	Mn	Ni	Si
		%	%	%	%	%	%	%	%	%	%	%
625	Zinc-base A	0.035	3.06	0.070	0.035	0.0014	0.0006	0.0005	0.013	0.031	0.019	0.018
626	Zinc-base B	.055	3.57	.020	.105	.0021	.0014	.0011	.039	.048	.048	.042
627	Zinc-base C	.135	3.89	.030	.023	.0082	.0049	.0042	.004	.014	.003	.024
628	Zinc-base D	.61	4.61	.009	.066	.0044	.0041	.0017	.009	.009	.030	.009
629	Zinc-base E	1.50	5.16	.094	.016	.013	.015	.012	.0008	.002	.008	.078
630	Zinc-base F	0.98	4.30	.030	.022	.0083	.0048	.0040	.003	.011	.003	.023

[a] Size: Bar segments, $1\frac{3}{4}$ in. square and $\frac{3}{4}$ in. thick.
[b] NBS Nos. 625, 626, and 627 correspond to ASTM alloy AG40A; NBS Nos. 628, 629, and 630 correspond to ASTM alloy AC41A.

ELECTRONIC SUBMINIATURIZATION TECHNIQUES

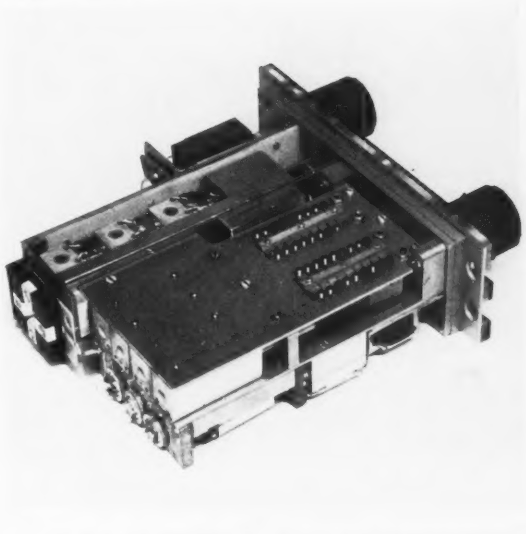
A NUMBER of practical procedures for fabricating subminiaturized electronic components and subassemblies have been developed at the Bureau. Methods for making commutator-type gain controls, temperature-compensated permeability tuned inductors, high temperature litz wire, and efficient IF transformers are but a few techniques resulting from a continuing program for subminiaturizing airborne electronic equipment for the Navy Bureau of Aeronautics. The unique construction problems that arose in this program led G. Shapiro and associates of the Bureau's engineering electronics laboratory to develop these fabrication methods.

Modern military aircraft are relying more and more on electronic equipment for their safe and effective operation. Because of the large amount of equipment that an airplane must carry, size and weight reduction are of utmost importance. The reduction in size of electronic subassemblies introduces construction problems wherever sufficiently small components are not commercially available. Moreover, because reducing the size of equipment means also reducing the amount of cooling surface to carry off the heat generated inside the chassis, components have to withstand temperatures up to 200° C. Thus, to achieve the goal of the subminiaturization program—size reduction to a practical minimum—departure from conventional construction techniques and the development of new techniques was necessary.

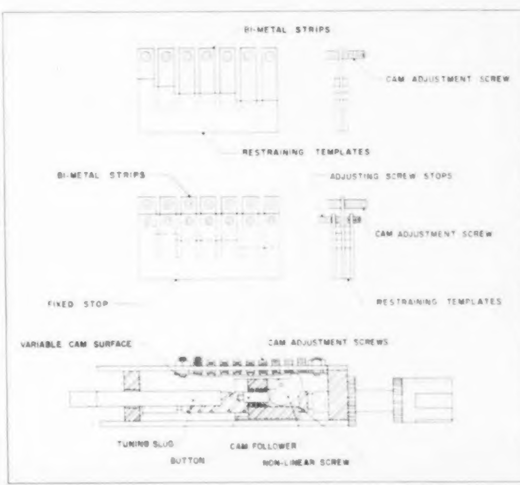
Commutator-Type Gain Control

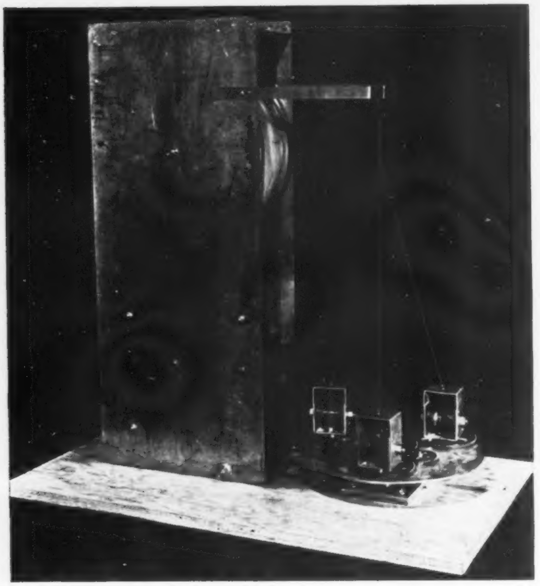
The essential element of the gain control is a strip of resistor tape[1] wrapped around 225° of a commutator fired on a piece of glass tubing, ½ in. in diameter and ¼ in. long. The commutator is composed of lines of silver conducting paint running axially on the surface of the glass tubing, thus providing taps to the resistor element.

Usually a large number of commutators can be fabricated at the same time from a single length of tubing. First, the tubing is chucked in a rotary indexing device. Silver paint rings of appropriate width are then sprayed or brushed onto the glass. When the paint has dried, a gravity-loaded stylus moving axially scrapes off the unwanted paint between each segment of the commutator. The equipment used at the Bureau provides a definition of 122 lines or segments per inch. After the lines have been scribed, the excess silver between each of the commutators is removed with a wide scribe and the long tube is fired at 1,100° F. The tube is then cut into ¼-in. lengths, leaving paint-free margins at the top and bottom of each commutator. After one rim is silvered and electrically grounded, the piece is refired, and a strip of NBS tape resistor placed on it and cured. In mass production, a template with closely-spaced spring-loaded scribes could scribe all lines in one.



Above: A low-frequency radio receiver subminiaturized for the Navy Bureau of Aeronautics. Unit occupies but 55 in.^{3}—less than one-fifth the volume of the original receiver that was constructed from conventional methods and components. In building this equipment, new fabrication techniques were developed wherever components of the required small size were not available. _Below:_ Temperature-compensated mechanism for permeability-tuned inductor. Variable cam surface, whose shape is controlled by adjustment screws, modifies the slug-penetration versus tuning frequency response of the inductor. By mounting the cam adjustment screws on bimetallic temperature-sensitive fingers, the cam surface is made to change to compensate for the effect of temperature on the magnetic material of the tuning slug.





Low-cost machine for winding litz wire by a simplified method. As table turns, spools also turn, thereby relieving torsion on individual strands of wire and reducing possibility of ceramic insulation stripping off. In use, a group of 2, 3, or 4 wires are twisted together, then three of these groups are twisted into the final bundle. As the final twist is tight, a binding cover is unnecessary.

Temperature-Compensated Permeability Tuned Inductor

A permeability tuner was designed to be tuned by ferrite slugs moving longitudinally inside inductors. The slugs are coupled to the mechanical assembly and the control knob through cam followers. Each follower rides against its own cam whose surface can be altered by a series of adjustment screws. As a slug is moved inside its tuning coil, the cam follower is raised or depressed by the contour of the cam surface, thereby advancing or retarding slightly the displacement of the slug. Thus the tuning curve can be modified for each individual slug.

The mounting of each cam adjustment screw on a temperature-sensitive bimetallic finger provides a different temperature-responsive correction for each position of the slug. Initially, all fingers are the same length, because they are fabricated by cutting a number of parallel slots, all the same length, into a rectangular piece of material. However, if a contoured restraining plate is clamped to the bimetallic plate, leaving different lengths of the ends of the fingers free, each finger will warp a different amount for a given temperature change. The longer the nonrestrained length of a finger, the greater the distance an adjustment screw is deflected by a change of temperature. Stops for the bimetallic fingers inactivate the correction at predetermined temperatures, so that the nominal temperature response curve of the inductor and tuning slug can predominate wherever desired.

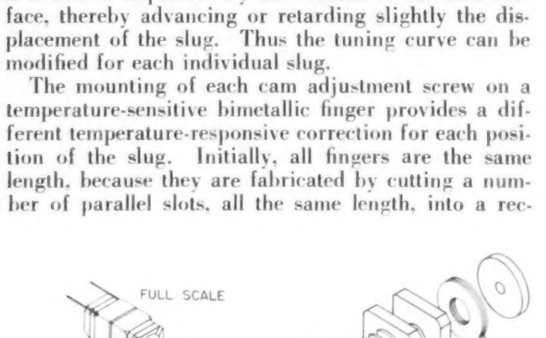
High-Temperature Litz Wire

Litz wire consists of a large number of insulated strands of fine wire woven together. Because litz wire with high-temperature insulation is not commercially available, a simplified method and a relatively inexpensive machine were devised to fabricate the wire from individual strands covered with ceramic-Teflon insulation.

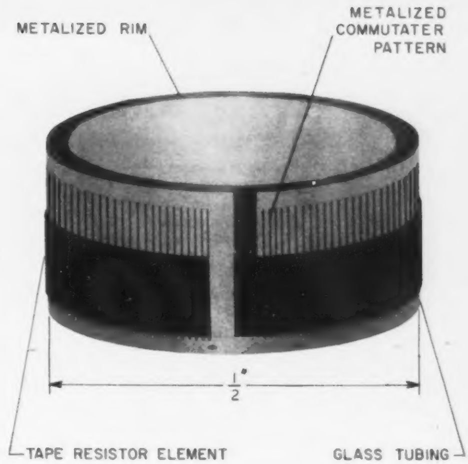
The machine is essentially a turntable which carries up to four spools of wire with their axes parallel to the turntable. The spools are mounted on frames geared to the main supporting shaft; as the turntable rotates, the spool frames turn at the same angular speed with respect to the turntable but in the opposite direction. As a result, no net twist is applied to the individual strands as they unwind from the spools. Because the torsion is relieved, the ceramic insulation will not separate from the wire. A group of 2, 3, or 4 strands are twisted together, then three groups are twisted into the final bundle. By making the final twist tight, a binding cover that may be costly and difficult to apply can be eliminated.

Intermediate Frequency Transformers

The subminiaturized IF transformer and its two associated capacitors are enclosed in a shield can measuring 0.520 by 0.582 by 1.375 in. Magnetic ferrite material is used instead of powdered iron to obtain a more constant *Q* and a greater tuning range with a given screw displacement. The coils consist of 5 sections of 60 turns each, supported by a thin-walled steatite bobbin permanently attached to a ferrite end



Exploded view of IF transformer assembly. When these components are assembled inside shield can (not shown), over-all size is little more than ½ by ½ by 1⅜ in. Bobbins are of steatite; spacer, sleeves, and end pieces of ferrite; capacitor cups of steatite; and O-rings of silicone rubber. A tuning screw of ferrite (not shown) extends through the holes in the centers of the components.



Subminiaturized gain control commutator. Base is glass tubing, upon which strip of tape resistor is fastened. Metalized commutator pattern provides taps at intervals along the tape for resistance variation.

piece. The inductor is placed in a closely-fitting ferrite sleeve. A single-coil assembly is therefore completely enclosed except at one end. In the transformer, two of these coils are placed with their open ends facing each other, but separated by a thin ferrite spacer. The thickness of the spacer controls the coupling between the coils. Adjacent to the outer ends of the transformer are silvered steatite cups that house mica capacitors. Silicone rubber retaining rings maintain the entire assembly under compression inside the shield can, and serve as elastic stop nuts for the tuning screws as well. At operating temperatures the circuits resonate nominally at 130 kc, and have a Q of about 60.

In constructing capacitors to go with this transformer, sheets of 2-mil mica are covered with silver paint, fired, and punched into washer shape with two tab extensions for external connections. To connect the wafers in parallel, the appropriate tabs are desilvered and the remaining are wrapped with wire and soldered into the silvered steatite cups. To prevent capacitors from acting as shorted transformer turns, a narrow gap is scraped on the circular pattern of each wafer to make it electrically discontinuous. The steatite cups are filled with an epoxy resin to protect the mica capacitors from humidity.

For further technical details, see Subminiaturization techniques for low frequency receivers, *NBS Circular 545, $0.50, available from the Superintendent of Documents, Government Printing Office, Washington 25, D. C.*; A subminiature low-frequency radio receiver, *NBS Tech. News Bul.* **35**, *68 (May 1951)*.

[1] A high-temperature adhesive tape resistor, *NBS Tech. News Bul.* **35**, *100 (July 1951)*.

Program in Mechanized Production of Electronics Terminated

THE NBS PROGRAM for automatic production of modularized electronic equipment, formerly code-named "Project Tinkertoy", was brought to its prescheduled conclusion in July 1956. Sponsored by the Navy Bureau of Aeronautics as a military preparedness measure, the initial phase of the program covered the development of the modular design and mechanized production concepts and culminated in a pilot plant facility. Since these concepts were first announced in 1953, the art has been further developed and full technical information has been released to private industry. A number of manufacturers of electronic components and equipment have shown extensive interest and have undertaken developments similar to the Bureau's. This broadened industrial activity and the further improvements now under way in industry make it appropriate for the Bureau to end its pilot plant research and development.

The NBS pilot plant, embodying the concepts of mechanized production of modularized equipment, produced electronic components for the Navy until 1956. At this time, the equipment was turned over to the Navy Bureau of Aeronautics who subsequently made it available to industrial concerns.

Evidence of the interest in the modular design and production technique from within the electronic industry continues to grow. At least three manufacturers are presently providing "Tinkertoy" wafers with components mounted according to their customers' specifications. Several additional companies have been producing and assembling modules into such military and civilian equipment as sonar, guided missiles, frequency meters, cathode ray oscilloscopes, radio and television receivers, and audio amplifiers. Thus, the interest and activity of private industry promises to lead to improved manufacturing systems and more versatile modules for both commercial and military electronic equipment.

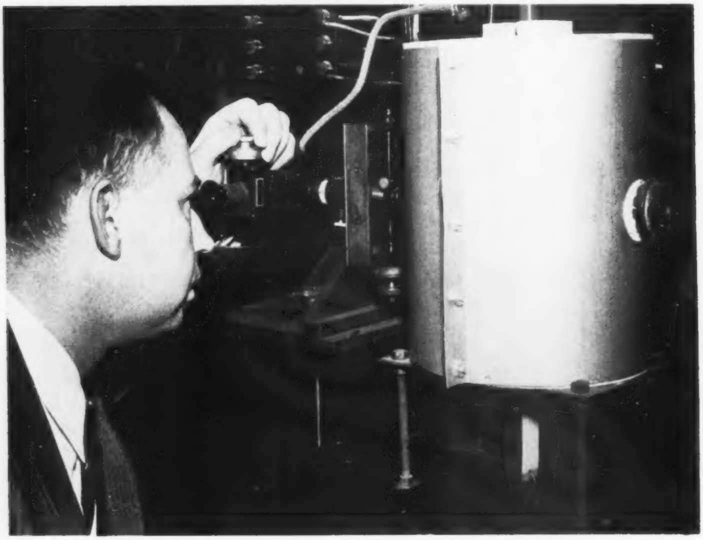
Although a major portion of the Bureau's recent program has been industrial indoctrination, technical research efforts were at the same time directed toward improvements in specific modular components and fabrication techniques. The quality of the tape-resistor was improved through (1) use of an NBS-developed curing oven that has extremely accurate temperature control, (2) development of new resistor formulations, and (3) new techniques of spraying and attaching resistors and capacitors to ceramic wafers. Results show that it is possible to make by mechanical means high-quality resistance and capacitance units that are stable and accurate over a wide range of operating conditions. Also under study was the adaptation of transistor devices and circuitry to the modular design system. Continuing throughout the entire term of the project were over-all system studies aimed at increasing production yields and reducing costs.

Effect of Ceramic Coatings on Creep of Alloys

REFRACTORY-TYPE ceramic coatings have come into widespread use on metal parts exposed to high temperatures, as in aircraft engines. The coatings protect the metal at high temperatures against the various corrosive atmospheres in which these parts normally operate. The ceramic coatings also affect the creep rates of some alloys under stress at high temperatures. The Bureau recently undertook a study of this creep behavior under different temperature-stress conditions. Results indicate that under some conditions a coating can reduce the creep rate as much as 50 percent, whereas under other conditions, a deleterious effect is observed. The investigation was carried out for the Wright Air Development Center by J. R. Cuthill, J. C. Richmond, and N. J. Tighe of the Bureau's enameled metals laboratory.

Of the various combinations of stress and temperature imposed, those at 1,975°F and 600 and 1,200 psi showed the greatest reduction in creep rates of the ceramic-coated specimens when compared with the uncoated specimens. Under these conditions the beneficial effect of the coating on the creep behavior of both 80Ni–20Cr alloys is sufficient to be of practical importance. At 1,975°F and 600 psi the creep rate of uncoated lot A specimens is higher than that of lot C. However, the reduction in creep rate imparted by the ceramic coating is so much greater in the case of the lot A alloy that the creep rate of the coated lot A specimens is significantly lower than that of the coated lot C specimens.

Extensive internal void formation was observed in the uncoated specimens tested at 1,975°F and at 1,900°F. Analysis showed that the uncoated specimens lost twice as much chromium as the coated specimens that were tested at the same temperature. Very little void formation was observed in the coated specimens that had been tested at either of these temperatures. Furthermore, no void formation was observed in coated or uncoated specimens tested at 1,800°F.

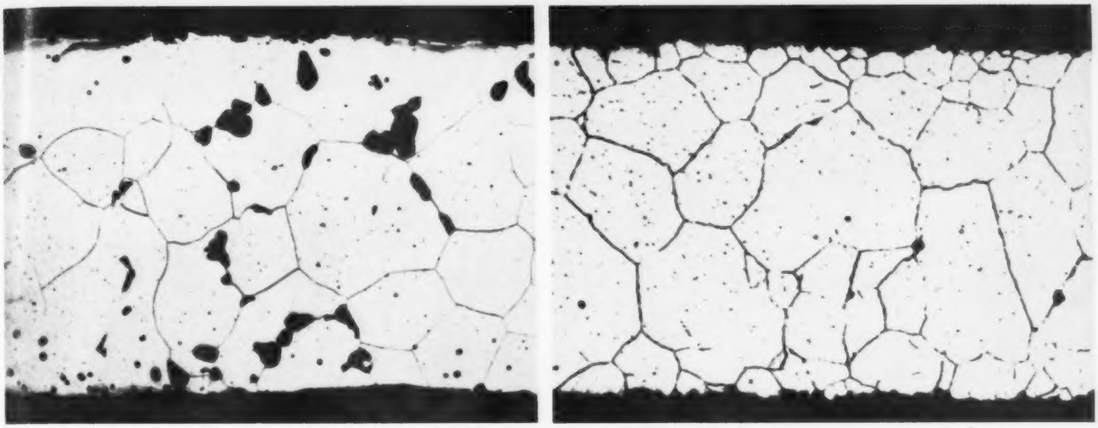


Operator observing creep behavior of ceramic-coated metal specimen in furnace. Results of a study of the creep behavior of alloys under different temperature-stress combinations indicate that a ceramic coating can reduce creep rate as much as 50 percent under some conditions. Ceramic coatings are widely used to protect metal at high temperature against corrosive atmospheres.

The creep characteristics of a metal can limit its useful life; thus the effect of ceramic coatings on creep properties is of considerable practical importance. The NBS ceramic coating N143 (see table 1), which contains cerium oxide for refractoriness, was chosen for this investigation. It was applied to specimens machined from thin sheet metal. The alloys studied are representative of materials that have good high-temperature oxidation resistance. These materials include two 80Ni–20Cr alloys (designated as "lot A" and "lot C") differing significantly in manganese, iron, and silicon content (see table 2). Both coated and uncoated samples were tested in a conventional controlled-temperature furnace designed for creep testing. Extension of the specimens was measured by sighting with a telescope through a window in the furnace onto a platinum extensometer fastened along the gage length of the specimen.

At 1,900°F and 900 psi and at 1,975°F and 600 psi the creep rate was virtually constant for the entire duration of the test for both lot A and lot C alloys. However, at 1,800°F and 2,200 psi the initial creep rate was comparatively low. After about 20 to 30 hours the creep rate rapidly increased for a few hours and then became gradually less again.

At 1,800° F and 2,200 psi the initial creep rate of ceramic-coated specimens was well below that of the uncoated specimens. The creep curves of the coated specimens usually remained below the curves of the



Photomicrographs of cross sections of fired coated and uncoated specimens. Uncoated specimen (left) shows considerable void formation, while little or no void formation occurred in the coated sample (right). Sections were cut transversely across the applied stress. Specimens are 0.010 in. thick. Uncoated specimen elongated 5.6 percent; coated specimen elongated only 3.7 percent.

uncoated specimens during the first 20 hours. However, during a period of rapidly increasing creep rate beginning about 20 to 30 hours after the start of the test, coated specimens generally showed an even greater rate of increase than the uncoated; fracture of the coated specimens usually occurred during this period. One ceramic-coated specimen, which did not fail under test for more than 1,200 hours, showed significantly greater creep after the first 100 hours than did the uncoated specimens.

In general, the results suggest that the N143 coating is not sufficiently fluid at 1,800° F to follow the deformation of the specimen at the very high strain rates occurring in these alloys when a stress of 2,200 psi is applied, and that it therefore cracks. Profuse cracking of the coating was observed in all of the coated specimens that failed in test at 1,800° F and 2,200 psi but in no other specimens. Presumably, at higher temperatures the N143 coating, being more plastic than at lower temperatures, was able to follow the deformation of the specimens at strain rates as high as those observed at 1,800° F and 2,200 psi.

For further technical information, see The effect of a ceramic coating on the creep behavior of some high-temperature alloys, *by J. R. Cuthill, J. C. Richmond, and N. J. Tighe, J. Am. Ceram. Soc. (in press).*

TABLE 1. *Composition of the NBS No. N143 high-temperature ceramic coating*

Mill batch composition of the N143 coating	
Ingredient	**Parts by weight**
NBS frit No. 435	67½
Cerium oxide, CeO_2	32½
Enameler's clay	4
Computed melted oxide composition of frit No. 435	
Oxide	**Mole percent**
SiO_2	51.02
BaO	25.51
BeO	10.20
P_2O_5	2.04
CaO	6.12
ZnO	5.10

TABLE 2. *Report of chemical analyses*[a] *of the two* 80Ni–20 Cr *alloys tested*

Constituent	Weight percent, 80Ni-20Cr	
	Lot A	Lot C
Cr	19.14	19.67
Mn	1.80	0.24
Si	1.28	.82
Fe	0.61	.10
Co	([b])	.07
Al	.10	.01
Zr	.09	.050
Ca	.038	.032
Cu	.03	.04
C	.03	.02
P	([b])	.01
Pb	([b])	.002
S	([b])	.001
B	([b])	.0005
Ni	Balance	79.04

[a] Furnished by manufacturers of the respective alloys.
[b] Not reported.

FIRE DETECTION IN AIRCRAFT

HEN FIRE BREAKS OUT in an aircraft engine space, it must be detected and quenched within seconds to avoid serious damage or possible loss of life. To provide design specifications for reliable, fast-acting fire detectors, the National Bureau of Standards has been studying flame characteristics that might be applied to aircraft fire detection systems. Results of this work indicate that reliability could be greatly increased by a system that would not respond unless several intrinsic properties of a flame were all present at the same time. These properties are (1) characteristic rate of increase of radiant flux, (2) sufficient level of radiant flux in the required spectral region, and (3) characteristic frequency of flicker. The investigation was undertaken for the Wright Air Development Center by W. F. Roeser and C. S. McCamy of the Bureau's fire protection laboratory.

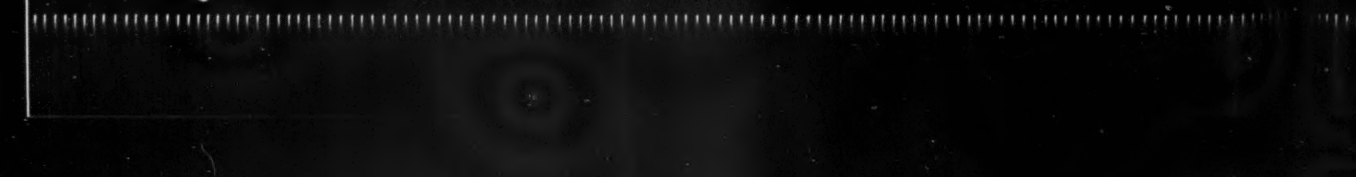
Too often in the past, frequent false alarms have undermined the airman's confidence in his fire detector, causing him to hesitate or neglect to take action when an alarm sounded. In some instances fires were not detected or were detected too late. Flight experience and fire tests under simulated flight conditions have clearly indicated that to be effective, a fire detector must invariably respond if, and only if, there is a fire and it must do so as quickly as possible.

Detectors are required to discriminate between fires and other phenomena under the most adverse environmental conditions, including temperatures from —65° to over 500° F, wind speeds over 500 mph, rain, hail, fog, salt spray, dust, oil, grease, fungus, fumes, vibration, and extreme pressure changes. A detector designed to respond to the radiant energy from flames for example must discriminate between flames and sunlight, lightning, gunfire, or beacons. The detector must survive a fire with flame temperatures over 2,000° F so that it can indicate that the fire is out and be ready to detect another fire a short time later. The aircraft designer demands that detectors have the least possible size and weight.

A survey of existing or proposed systems revealed a number of ingenious applications of various physical principles. Radiant energy detectors seemed the most promising because a single detector can monitor a large space. However, for development of improved designs, more fundamental data were needed on the characteristics of flames involved in aircraft engine fires. Therefore, a study was undertaken at the Bureau of the radiation and flicker of flames.

Flame Spectra

The more important flammable materials found in aircraft engine spaces include such liquid hydrocarbons as engine fuel, lubricating oil, and hydraulic fluid. In a typical engine fire involving these flammable liquids, oxygen diffuses into the flames from the surrounding atmosphere, producing a "diffusion flame" which emits essentially the same continuous spectrum for each of the burning liquid hydrocarbons. Experiments were performed that showed that various aircraft fuels premixed with air before burning produced nearly identical



CIFT ENGINE SPACES

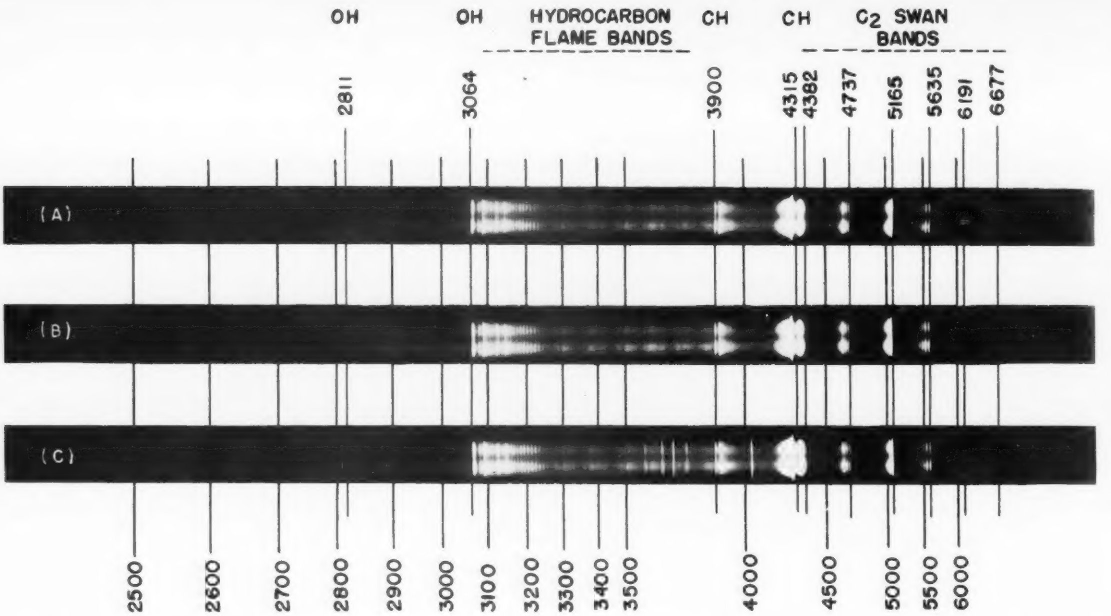
spectra except for the lead lines in the spectra of leaded fuels. As a result of these spectrometric studies it was concluded that for the design of radiant energy detectors the same spectral region would be suitable for all fuels likely to be involved.

Radiation Measurements

The radiant intensities of the flames of various fuels were measured in five wavelength intervals from 0.24 micron in the ultraviolet to 2.5 microns in the infrared. To measure the fluctuating radiant intensity in all parts of the spectrum simultaneously, photoelectric detectors were used with suitable filters and the output signals were recorded on a multichannel recording oscillograph. A radiation-pyrometer detector with appropriate filters measured the radiance of flames in several infrared regions extending to 9.5 microns.

The investigation showed that flames of the type likely to occur in engine spaces emit energy throughout the spectrum but emit far more in the near infrared than in any other wavelength region. Some parts of the spectrum were found to be unsuitable for use in fire detection. The strong absorption of radiant energy by oil, grease, and soot in the visible and ultraviolet parts of the spectrum would prevent reliable detection of energy of those wavelengths. The visible part of the spectrum is also considered undesirable because of the high intensity of sunlight and skylight in that region. The most suitable part of the spectrum for fire detection therefore appears to be the near infrared.

Above: **Operator measuring radiant intensity of a flame in various regions of the spectrum with a five-band spectroradiometer. This instrument has been used in studying flame characteristics that might be applied to the design of aircraft fire detection systems. Results of study indicate that detectors can be designed to discriminate reliably between fires and other phenomena if several intrinsic properties of a flame are all present at the same time.** ***Below:*** **Oscillograph record of the variation in radiant intensity of a flame known as "flicker." Lower part of oscillogram is 40 cps timing trace. Electronic wave analysis of flicker amplitude shows a sharp maximum at some frequency between 3 and 15 cps. Thus flicker provides a valuable distinguishing feature for fire detector design.**



To provide design specifications for aircraft fire detection systems, flame spectra, radiation, and flicker were studied. This illustration shows typical flame spectra for three aircraft engine fuels. It was concluded that for the design of radiant energy detectors, the same spectral region would be suitable for all fuels likely to be encountered. Extra lines in bottom spectrum are due to lead in the fuel. Wavelengths in angstrom units.

The characteristics of various window materials were considered with respect to ambient conditions and their effects on discrimination. Of the materials capable of withstanding the ambient conditions expected, fused quartz appears to be the most satisfactory because it transmits well in the infrared out to about 3.8 microns. Moreover, it transmits a somewhat larger percentage of the energy from flames than from a hot metal background having the same radiance as a flame, thus providing a measure of discrimination between these sources.

Increase in Radiation

Although the engine radiance may approach that of a flame, the engine takes a much longer time to heat up than the fuel vapors take to burst into flame. Measurements show that the flames to be expected in accidental fires in engine spaces reach full intensity about a quarter of a second after ignition, whereas the engine takes over a minute to warm up. This difference in rate of increase of radiation provides another distinguishing feature for detection purposes.

Flicker Measurements

A high level of radiant flux or a rapid rate of rise could be caused by events other than fires. One of the recognized attributes of flames is their natural tendency to flicker—to produce a fluctuating radiant intensity. This effect occurs simultaneously in all parts of the spectrum studied. The nature of flicker was observed with high-speed motion pictures and electronic wave analysis of the output of photoelectric detectors.

The motion picture measurements indicate that variation in projected flame area rather than variation in radiance accounts for a large part of the flicker of flames. Electronic wave analysis provided flicker amplitude distribution curves for the various flames studied. In many cases, these curves have a sharp maximum at some frequency between 3 and 15 cps. The ratio of the root mean square flicker amplitude to the average radiant intensity for various flames ranges from about 0.1 to about 0.4 for burning liquids. These results indicate that flicker provides another valuable distinguishing feature for detector design. Because moving engine parts or other periodic phenomena might cause fluctuations in the radiant flux, flicker was not recommended for use alone as a fire detector, but rather in combination with the characteristic rate of increase of radiant flux and sufficient radiant intensity in the right spectral region.

For further technical details, see A five-band recording spectroradiometer, *by C. S. McCamy, J. Research NBS* **56,** *293 (1956) RP2678;* Principles of fire detection in aircraft engine spaces, *by W. F. Roeser and C. S. McCamy (may be purchased from the Office of Technical Services, Department of Commerce, Washington 25, D. C., price $3.00).*

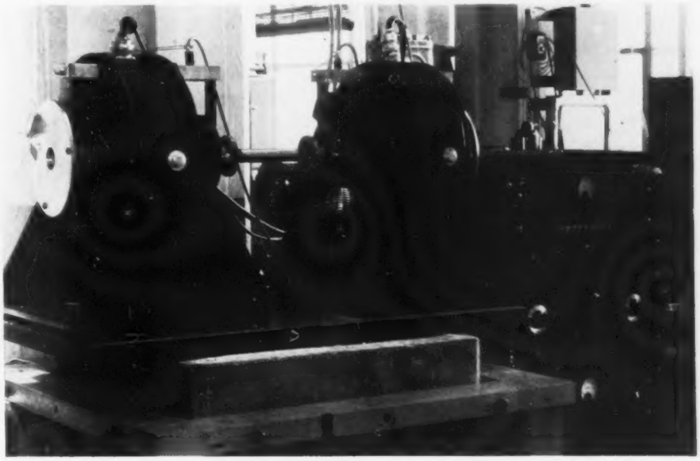
Electrodynamic Standards for Vibration Pickups

THE BUREAU has developed a method for standardizing electrodynamic calibrators that makes possible a limited NBS calibration service for vibration pickups measuring displacement, velocity, or acceleration.[1] The method is based on research conducted by S. Levy and R. R. Bouche of the Bureau's engineering mechanics laboratory with the combined support of the Bureau and the Diamond Ordnance Fuze Laboratories, Department of the Army.

Thousands of vibration pickups are now in use by Government and industry for testing missiles, aircraft, ships, surface vehicles, and other types of equipment. The successful performance of such machines and the safety of operating personnel depend on the accuracy of observations made with the pickups, and therefore on the accuracy of their calibration. To meet this need for accurate vibration measurements, the Bureau has for some time been investigating various methods for calibrating these pickups.

The NBS method for standardizing the calibrator is based on an improved mathematical analysis of the problem—a more comprehensive reciprocity theory. This method avoids all direct measurement of the vibratory motion itself. It also has the advantage that it can be used above as well as below certain resonances in the calibrator. It is only necessary to measure frequencies, currents, and voltages in the calibrator when (1) several known masses are attached to the mounting table and (2) when the calibrator is forced to vibrate by an external vibration exciter.

The result of the standardizing procedure is summed up in two quantities, a and b (see below), which characterize the calibration factor of the calibrator. This factor then expresses the relation between voltage output of the calibrator and the velocity of the mounting table. At higher frequencies, starting at about 900 cycles per second, it is also necessary to know the mechanical impedance of the pickup being calibrated.



Apparatus used in second part (voltage ratio measurements) of reciprocity method for standardizing electrodynamic vibration-pickup calibrators. In this part of the procedure another electrodynamic calibrator (extreme left center) is mechanically connected to the calibrator being standardized and produces sinusoidal motion in its moving parts.

If not already known, this can easily be measured with the standardized calibrator.

The electrodynamic calibrator for vibration pickups consists of a vibration exciter with a built-in vibration measuring device. It produces mechanical vibrations by electrical means and, simultaneously, generates an electrical output that depends on the vibration. The calibrator is standardized by determining the relationship between its electrical output and the vibratory motion.

Once an electrodynamic calibrator is standardized, the procedure for calibrating a pickup is straightforward. The pickup is attached to the mounting table of the calibrator and is set in vibration at the desired amplitude and frequency. The amplitude can be accurately set as a result of the standardization procedure and the frequency can be accurately measured. It then remains only to compare the voltage output of the calibrator with that of the pickup.

In calibrating a pickup, both the magnitude and phase of the pickup calibration factor can be determined, if desired. Pickups calibrated for amplitude only would be suitable for making many vibration measurements in structures. Those calibrated for both amplitude and phase would be suitable as secondary reference standards for governmental and industrial laboratories, or for vibration measurement on structures where phase measurement is desired.

Electrodynamic Calibrator

The electrodynamic calibrator for which the present method has been developed has three basic components—driving coil, mounting table, and velocity-

sensing coil. These components are the principal moving parts. In the calibrator studied, these parts joined by a shaft form a single mechanical unit that is suspended from a frame by leaf springs. Also attached to the frame are a field magnet coil near the driving coil and a permanent magnet near the velocity-sensing coil. When alternating current is passed through the driving coil, its magnetic field interacts with that of the field coil, causing the moving parts to vibrate. At the same time, because of the motion relative to the permanent magnet, an alternating voltage is generated in the velocity-sensing coil.

In using the calibrator, the pickup to be calibrated is attached to the mounting table and its electrical output is compared with that of the velocity-sensing coil. If this comparison is to be significant, however, the calibrator must be standardized. That is, the relation between the electrical output of the velocity-sensing coil and the velocity of the table must be determined. The reciprocity method enables this relation to be calculated without requiring a detailed knowledge of the structure of the calibrator.

Reciprocity Theorems

Reciprocity theory was first applied to electrical circuits. In the case of a passive linear network, the basic theorem is that if a source of emf is placed in branch A of the network, the current produced in branch B is the same as the current that would be produced in branch A if the same emf were inserted in branch B. In principle, a corresponding theorem holds for any linear system, including one made up of both electrical and mechanical components. As applied to the electrodynamic calibrator, the reciprocity theorem used states that the ratio of mechanical force at the mounting table to the driving-coil current when the velocity of the table is zero (i. e., when it is held fixed) is equal in magnitude and opposite in phase to the ratio of the terminal voltage of the driving coil to the mounting table velocity when the driving-coil current is zero (i. e., when its circuit is open).

The reciprocity technique was applied by Bureau scientists to the calibration of microphones as early as 1940.[2] In 1948, London, Trent, and Thompson[3] showed how the technique could be used to calibrate electromechanical transducers, provided certain conditions are satisfied. One of these conditions is that the connections between transducers be rigid. This method was applied in 1953 to an electrodynamic calibrator by J. C. Camm, then of NBS, in a project supported by the Office of Naval Research. The present work extends the theory by eliminating some of the restrictive assumptions about the structure of the calibrator.

In its present form, the theory applies to an electrodynamic calibrator operating in any frequency or amplitude range in which it can be considered linear. Neither the internal structure nor the magnet assembly need be assumed rigid. It applies, for example, not only at low frequencies and at frequencies near certain resonances, but also at frequencies above axial resonance when the driving coil and mounting table move in opposite directions. In addition, the extended theory takes account of electrical coupling between different parts of the same coil and between parts of different coils.

Standardization Procedure

Standardization of the calibrator determines the calibration factor, F, the ratio of induced voltage in the velocity-sensing coil to the mounting table velocity. This factor depends mainly on the characteristics of the calibrator itself, but is also influenced at higher frequencies by the mechanical impedance of the pickup attached to the table.

When a vibration pickup is attached to the table and the driving coil is energized with alternating current at any particular frequency, the theory shows that

$$F = a + bY_p, \qquad (1)$$

where Y_p is the mechanical impedance of the pickup and a and b are constants that depend on the construction of the calibrator. All the symbols stand for complex numbers in the manner used in alternating-current theory. Thus, Y_p is the complex number that represents in magnitude and phase the ratio of the sinusoidal force applied to the pickup to the resulting sinusoidal velocity. The aim of the standardization procedure is to determine the constants, a and b. In computing their values, transfer admittance and voltage ratio measurements are made.

The transfer admittance, G_w, which is the ratio of driving-coil current to velocity-sensing coil voltage, is measured with each of several weights, W, attached to the mounting table. The transfer admittance, G_0, with no weight attached, is also measured. Then for each weight attached to the table, the ratio $W/(G_w - G_0)$ is computed. This procedure is repeated at each frequency for which the values of a and b are desired. For each frequency, the real and imaginary parts of the computed ratio are plotted against W.

For the voltage ratio measurements, the mounting table of the calibrator being standardized is mechanically connected to that of another electrodynamic calibrator or other vibration exciter. The driving coil in the latter is energized and the ratio R, of the open-circuit voltage generated in the volocity-sensing coil to the open-circuit voltage generated in the driving coil is measured. This is done for each of the frequencies used in the transfer admittance measurements. The voltage ratio measurements are made, of course, on the calibrator being standardized.

Once these measurements have been made, the constants a and b are computed from the following equations:

$$a = 0.01711\sqrt{j\omega JR}, \qquad b = 6.601\,Q\sqrt{R/(j\omega J)} \qquad (2)$$

where ω is the frequency in radians per second and j is the unit imaginary vector. The terms J and Q are the ordinate intercept and slope, respectively, of the plot of $W/(G_w - G_0)$ versus W. This completes the standardization procedure as the calibration factor

can be computed from eq (1) if the mechanical impedance of the pickup to be attached to the mounting table is known.

The procedure is illustrated by results obtained for a typical electrodynamic calibrator with a nominal 50-lb driving force rating. Calibration factors for this instrument were computed from eq (1) for pickups with mechanical impedances corresponding to weights, W, of 0, 0.5, and 1.0 lb (Y_p is then equal to $j\omega W/g$, where g is the acceleration of gravity, 386 in./sec²). The magnitude and phase angle of these calibration factors were plotted against frequency. The graph shows that, for this particular calibrator, the calibration factor is independent of frequency and pickup weight up to 900 cps.

Calibration of Pickups

Ordinarily, before a pickup can be calibrated, its mechanical impedance, Y_p, must be known in order to use eq (1) to obtain the calibration factor of the calibrator. If the Y_p of the pickup is not known, it can be measured on an electrodynamic calibrator standardized by the reciprocity method. The theory shows that

$$Y_p=j\left(\frac{\omega}{386}\right)\left(\frac{J(G_p-G_0)}{1-Q(G_p-G_0)}\right) \tag{3}$$

where G_p is the transfer admittance (ratio of driving coil current to velocity-sensing coil voltage) with the pickup attached to the table. The values of J, Q, and G_0 are known from the standardization of the calibrator.

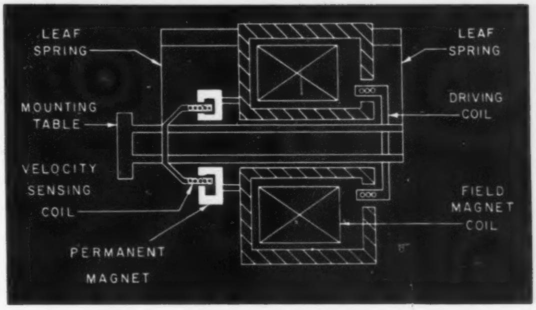
One method of calibrating a pickup is to energize the driving coil of the calibrator at the desired frequency and drive the calibrator at the desired amplitude as indicated by the voltage in the velocity-sensing coil. From this indicated voltage and the value of F obtained from eq (1), the velocity of the mounting table is found by a simple division, because F is the ratio of velocity-sensing coil voltage to mounting-table velocity. The output of the pickup corresponding to this velocity is then measured. The calibration factor of the pickup is then the ratio of the output of the pickup to the velocity of the mounting table.

A second method is to measure G_p and also the transfer admittance, I/E_p, which is the ratio of the current, I, in the calibrator driving coil to the voltage output, E_p, of the pickup. The calibration factor, F_p, of any accelerometer is then given by

$$F_p=\frac{G_p}{I/E_p}\cdot\frac{gF}{j\omega}, \tag{4}$$

where $gF/j\omega$ is the acceleration calibration factor of the calibrator. The same method can be used to calibrate velocity- and displacement-type pickups, except that eq (4) must be modified by replacing the acceleration calibration factor by the calibration factors for velocity (F) or displacement ($j\omega F$), respectively.

For example, in the case of a piezoelectric accelerometer, the transfer admittance, G_p, was measured with



Schematic cross section of electrodynamic vibration-pickup calibrator. Driving coil, mounting table, and velocity-sensing coil form a mechanical unit that is set in vibration when alternating current is passed through the driving coil and field magnet coil. The vibration causes the velocity-sensing coil to cut lines of force of the permanent magnet, generating a voltage in the velocity-sensing coil. When a vibration pickup is to be calibrated, it is attached to the mounting table and the electrical output of the pickup is compared with that of the velocity-sensing coil.

the device attached to the mounting table and its mechanical impedance, Y_p, was found from eq (3). The other quantities in eq (3) were known from the calibrator standardization data. The calibration factor, F, could then be obtained from eq (1). After measuring the transfer admittance, I/E_p, the calibration factor of the pickup, F_p, was computed from eq (4).

The calibration of a variable-resistance accelerometer was performed in a similar manner. In determining the calibration factor for such a pickup at frequencies other than those at which the calibrator was standardized, it was necessary to interpolate for a, b, R, and Q, and to compute J from eq (2). This interpolation was used only at frequencies below 900 cps, in which range the interpolation leads to no appreciable error, for the calibrator used.

It was found in the calibration of these pickups that the term, bY_p in (1) was negligibly small compared to the term, a, at frequencies up to 900 cps. In such cases the procedure in both of the above methods is considerably simplified. Once the calibrator has been standardized, it is easy to predict the frequency range in which the term, bY_p, can be neglected.

Calibrator Resonances

Among the resonant conditions of the calibrator studied are the following, in their usual order of appearance with increasing frequency: Resonance of mounting table and coils as a rigid body on the guiding leaf springs, local resonance in the leaf springs, transverse resonance of the shaft connecting mounting table and driving coil, longitudinal resonance of the same shaft, and local resonance in mounting table or coils.

Longitudinal resonance of driving coil relative to velocity-sensing coil reduces the accuracy of the reciprocity calibration over a small frequency range. This

is because R at resonance is very small and therefore difficult to measure and because at resonance the large amplitude of the driving coil may exceed its linear range.

Transverse motion from any source invalidates the reciprocity method, because the latter requires the mounting table to have uniaxial motion. Usually, transverse motion occurs at frequencies for which the leaf springs or shaft are in transverse resonance. The leaf springs of some calibrators can be detuned, thus changing the frequency at which resonance occurs, by repositioning small weights attached to them. When standardizing the calibrator and calibrating vibration pickups, care is taken to avoid frequencies at which transverse motion is present.

Calibrator Performance

Several electrodynamic calibrators standardized by the reciprocity method are now in service at the Bureau for the calibration of vibration pickups. A redetermination of the constants a and b for one of the NBS calibrators showed no significant change after the lapse of a year. With respect to frequency, the calibration factors of the standards have been found to be constant within 1 percent up to 900 cps. At higher frequencies the calibration factor is known with somewhat less accuracy because of flexibility in the standard as a result of longitudinal resonances. This flexibility changes the electromechanical characteristics of the standards and results in less stability at the higher frequencies. Plans are under way to modify the standards to achieve an accuracy of 1 percent at higher frequencies.

[1] *For further technical details, see* Calibration of vibration pickups by the reciprocity method, *by S. Levy and R. R. Bouche, J. Research NBS* **57**, *227 (1956) RP2714.*

[2] Absolute pressure calibrations of microphones, *by R. K. Cook, J. Research NBS* **25**, *489 (1940) RP1341.*

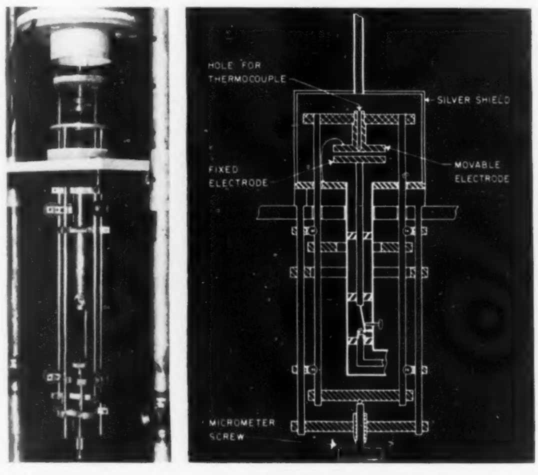
[3] The absolute calibration of electromechanical pickups, *by H. M. Trent, J. Appl. Mech.* **15**, *49 (1948)*; Reciprocity calibration of primary vibration standards, *by S. P. Thompson, Naval Research Laboratory Rept. F-3337, 8 p. (Aug. 16, 1948); London's work is reported in* The absolute calibration of vibration pickups, *NBS Tech. News Bul.* **32**, *8 (1948).*

VERSATILE SPECIMEN HOLDER FOR DIELECTRIC MEASUREMENTS

THE BUREAU has designed a versatile specimen holder to be used in conjunction with a bridge or resonant circuit in determining electrical properties of dielectrics at elevated temperatures. The instrument is useful over wide temperature and frequency ranges in making precise measurements of the dielectric constants, dissipation factors, and thermal expansions of insulating materials. Developed for the Army Ordnance Corps by A. H. Scott of the Bureau's dielectrics laboratory, the device is expected to be of value in the study of the electrical properties of high polymers and ceramics.

Many new plastic and ceramic insulating materials have been developed in recent years for high-temperature applications. Consequently, there has been a growing need to classify these materials according to their stability at elevated temperatures and the effect that temperature has on their electrical properties. This classification requires methods of measuring electrical properties at high temperatures with an accuracy comparable to that available at room temperature. Moreover, because of the difficulty in preparing specimens having identical electrical properties, it is usually necessary to use a single sample for an entire series of measurements over a given temperature range. Devices previously developed have been limited to use at a single temperature or over a comparatively small range of temperatures, and did not measure thermal expansion of the specimen, or were not sufficiently precise.

The device is essentially a pair of gold-plated stainless steel electrodes, about 2 in. in diameter, between which the dielectric specimen is placed. The lower



Photograph and cross-sectional drawing of specimen holder developed for use in conjunction with a bridge or resonant circuit in determining electrical properties of dielectric materials at elevated temperatures. Specimen is placed between two electrodes. Silver shield that provides electrostatic shielding is enclosed in electrically heated oven. Micrometer measures expansion of specimen. Thermocouple is placed in hole in top electrode, close to specimen.

electrode is stationary and the upper electrode can be moved up or down to accommodate the thickness of the specimen. An electrostatic shielding case of silver covers the electrodes and the case in turn is enclosed in an electrically heated oven.

The silver shield is removable for insertion of the specimen. A tube brazed to the top of the cover extends out of the top of the oven, thus permitting the insertion of a thermocouple for measuring the temperature of the specimen. A hole bored down the axis of the upper electrode to within 0.5 mm of its lower surface permits placing the thermocouple close to the specimen. Temperature of the oven can be controlled to within 0.5°C by a commercial controller. The instrument can also be surrounded by a cooling unit for measurements down to −40°C.

The upper electrode is mounted on a rigid frame constrained by a set of guide wheels to move only in a direction parallel to the axis of the electrodes. Guide wheels are mounted on a stationary frame fastened to the base plate of the silver case surrounding the electrodes. The position of the movable frame and the upper electrode is controlled and measured by a micrometer at the bottom of the entire assembly. The pressure on the specimen is therefore the weight of the frame and the electrode. If desired, this weight can be supported instead by the micrometer to keep the specimen from being deformed.

The supporting frames, the electrodes, and the thin-walled tubing supporting the insulated lower electrode, are all fabricated from stainless steel to minimize differential expansion. The residual expansion can be determined experimentally by resting the upper electrode on the lower electrode and then noting the change in micrometer reading after equilibrium is established at each operating temperature. The curve resulting from plotting the dimensional change versus the temperature determines the corrections to be applied to the micrometer reading in making actual measurements.

The upper electrode is electrically grounded to the case by a stranded silver wire. At frequencies above 1 Mc, the inductance of the leads to the high-temperature holder introduces errors in the capacitance and dissipation factor measurements. These errors are negligible for frequencies below 1 Mc and are readily evaluated for frequencies between 1 and 10 Mc by a series of measurements of the holder with air as a dielectric. The holder cannot be used at frequencies above 10 Mc because the resonant frequency of the holder is only about 60 Mc. The holder is also used for d-c measurements.

For further technical details, see Measurement of dielectric properties at temperatures up to 500° C, *by A. H. Scott, P. Ehrlich, and J. F. Richardson, ASTM Special Technical Publication, No. 161, 1954:* Precision measurements of dielectric constant over a wide range of frequencies and temperatures, *by A. H. Scott, Proc. ISA, Vol. 11, 1956, Paper No. 56-8-2.*

DIELECTRICS SECTION ESTABLISHED

A NEW SECTION for fundamental investigation of the dielectric properties of matter has been established at the Bureau. Designated the Dielectrics Section, the new group will be in the Electricity and Electronics Division.

The primary purpose of the Dielectrics Section will be to augment the present fund of basic knowledge in the field of dielectrics by conducting experimental and theoretical studies on substances that act as electrical insulators. Specific areas of research will include the dielectric properties of polymeric systems, standard substances, the direct current conductivity of dielectrics, methods of increasing the accuracy of dielectric measurements on solids at audio and lower frequencies, and the fundamental studies on molecular and ionic crystals.

The new section will be headed by John D. Hoffman, formerly of the Polymer Structure Section.

The Radio Standards Division of the NBS Boulder Laboratories is continuing with its research and development on measuring techniques and standard samples at radio and microwave frequencies under the direction of D. M. Kerns and J. L. Dalke.

Circular on Electrical Standardizing Laboratories

SINCE WORLD WAR II there has been a sharp increase in the number and scope of standardizing laboratories in the United States. Although the particular situations vary in each laboratory, each one must correlate its reference standards with those of the Bureau. These laboratories also have a great many common problems in their work of maintaining and disseminating the units of measurement.

The Bureau has prepared a circular suggesting techniques and principles that experience has shown to be useful in such operations. Although it covers explicitly only the field of electrical measurements, many of the principles involved are equally applicable in other kinds of measurement.

For the sake of clarity, the measuring instruments and apparatus are divided into five categories. They are: Reference standards, working standards, comparison equipment, interlaboratory standards, and shop instruments and measuring apparatus.

The new publication entitled *Suggested Practices for Electrical Standardizing Laboratories*, National Bureau of Standards Circular 578, by Francis B. Silsbee, 9 pages (15 cents), is available from the Government Printing Office, Washington 25, D. C.

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Contents

Publications of the National Bureau of Standards

Journal of Research of the National Bureau of Standards, volume **57**, No. 6, December 1956 (RP2720 to RP2726 incl.) 60 cents. Annual subscription $4.00.

Technical News Bulletin, volume **40**, No. 12, December 1956. 10 cents. Annual Subscription $1.00.

Basic Radio Propagation Predictions for March 1957. Three months in advance. CRPL-D 148. Issued December 1956. 10 cents. Annual subscription $1.00.

Research Papers

Journal of Research, volume **57**, *No. 6, December 1956. 60 cents. Single copies of Research Papers appearing in the Journal are not available for sale. The Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., will reprint 100 or more copies of a Research Paper. Request for the purchase price should be mailed promptly to that office.*

RP2720. Properties of barium titanium silicate glasses. Given W. Cleek and Edgar H. Hamilton.

RP2721. Scavenging characteristics of a two-stroke-cycle engine as determined by skip-cycle operation. P. M. Ku and T. F. Trimble.

RP2722. Synthesis of β-gentiobiose-1-C^{14}. Robert Schaffer and Horace S. Isbell.

RP2723. Hydration of aluminous cements and its relation to the phase equilibria in the system lime-alumina-water. Lansing S. Wells and Elmer T. Carlson.

RP2724. Axial performance of spectacle lenses. Francis E. Washer.

RP2725. A survey of negative ions in mass spectra of polyatomic molecules. Robert M. Reese, Vernon H. Dibeler, and Fred L. Mohler.

RP2726. Heat conduction through insulating supports in very low temperature equipment. R. P. Mikesell and R. B. Scott.

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